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The Calculating Effectiveness Increasing of Detecting Air Objects by Combining Surveillance Radars into The Coherent System

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ABSTRACT

The article proposes the creation of a small basic synchronous radar network based on two-coordinate surveillance radars, which will enable to increase detection range or detection efficiency for equal other parameters of air objects. Autonomous operation of such radars is not efficient enough, since radar information is combined after the detection of radar objects. The additional complexity will be due to the using of existing radars with mechanical rotation antenna systems in the azimuth plane as elements of the system. The energy contained in the electromagnetic field structure is more effectively used in the system than in autonomous monostatic two-coordinate radars. There will be an increase in the energy potential of the system due to the increase in the antenna array gain due to the narrower antenna array pattern beam compared to the autonomous radar. Suggestions for construction of an automated system for technical diagnostics of objects of radio-electronic equipment on the example of radars.

Key words: radar, air surveillance, radar, antenna array, antenna gain, detecting of air objects, the coherent system.

1. INTRODUCTION

From the analysis of the experience of latest military conflicts, hybrid wars, regional military conflicts, it has been established that the means of conducting of radar observation of airspace with sufficient effectiveness is the different radars [1]–[3].

Detection of airborne objects is hindered by a decrease in their effective scattering surface [4]–[7].

Also unmanned aerial vehicles (UAV) become the main means of aerial surveillance. UAVs can be used throughout the altitude range and have different purpose [7]–[13].

In such circumstances, a high-quality improvement in the performance of the radar will be possible not so much by increasing the radar field, but to a greater extent by combining the radar information of individual autonomous existing radars into different networks using modern information systems, technologies and recent advances in radar [14]–[21].

1.1 Problem analysis

Many different types of multi-radar systems are known to be created and have already been created. The positions of the elements of such systems can be transmit or receive, to be combine receive transmit, or all only receive (passive system), which uses third-party sources of radiation or proper radiation of aircraft [2]–[7], [11]–[12], [14], [22]–[24].

The positions or elements of such systems are spatially separated from each other. Radar information can be processed individually if the elements of the system are single-position radars, and the aggregation of information is carried out only at the level of aircraft markers or trajectories at a single centre, which can be combined with one position or individually. This path does not use the energy contained in the electromagnetic field in the space around the air object sufficiently efficiently [2]–[7], [11]–[12], [14].
At the center of information processing, it is advisable to carry out the initial baseline processing of radar information. The effectiveness of such processing will depend on the degree of coherence that is ensured in the system. The development of information technology and the use of special high-speed processors in signal processing and radar information, as well as new high-speed equipment enhance the functionality of radar networks [11]–[12], [14], [25]–[27].

It is known [1], [11]–[12], [14] that under difficult conditions of air space conditions the radar field is increased by increasing the number of radars, moving additional mobile radars to special positions to ensure a continuous radar field at low altitudes.

Such radars have high mobility. Due to this, in some areas a much higher ratio of the overlap of detection zones is created. In such districts there should also be backup radars for alternating duty or combat work in the event of a failure main. The energy of the radar system is not fully utilized, as each radar receives only its own echo.

The proximity of radar positions to the front line does not enable to extend the far limit of the radar field for detection of UAVs by imbed radar posts. The only possible way to solve this problem is to increase the range of detection of low-impact objects in some of the most dangerous destinations that require additional efforts [1], [11]–[12].

An effective way to improve radar performance is to combine them [11]–[12], [14], [25]–[27]. The advantage of this solution is the ability to accept the reflected from the target signal by all receiving positions, the use of system effects that will appear after the integration of autonomous radars in synchronous multi-radar systems with the implementation of coherence of different degrees and joint reception of echoes [11]–[12], [14], [25]–[27].

One of the key issues determining the feasibility of creating such systems is the provision of compatible air space surveillance across all spatial-distributed radars.

The purpose of the article is the calculating effectiveness increasing of detecting air objects by combining surveillance radars into the coherent system.

2. MAIN MATERIAL

A large number of existing one-position radars are currently in use. They are reliable radars air surveillance. Their parameters no longer meet the requirements of modern radars. Nevertheless, they continue to be actively used and their numbers are large enough. There are several ways to increase the efficiency of radars: increasing energy potential, increasing directional properties of antenna systems, use of adaptive antenna arrays.

One way to obtain high radiation directivity is to use an antenna array - a system of directional antennas, in some way located in space and excited by currents with the required ratio of amplitudes and phases. Compared to single antennas, the antenna array enable to obtain a narrower directional pattern.

It is proposed to integrate standalone monostatic radars into the system. Such a system would be a sparsed antenna array. Consider a one-dimensional enable of elements of a sparse antenna array. It is cost effective to select the existing radars as elements. They are simple in design, reliable compared to even modern but sophisticated equipment. In addition to working as part of the system, they reserve the ability to work offline. The additional ability to work in a multi-radar system in any combination does not limit the detection resources provided by developers.

It is proposed for ease of calculation to use linear placement of elements in the space. If the distance between adjacent elements of the antenna array remains constant along the entire array, then such antenna array is called equidistant [28]–[30]. In practical terms, linear equidistant placement is difficult to implement. Therefore, we will consider the distances between the elements to be equal (Fig. 1):

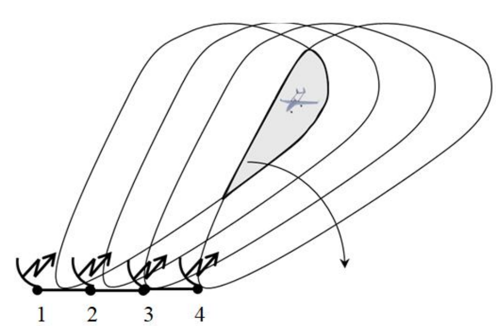


Figure 1: Methods of Linear equidistant situation of the antenna array four-element multi-radar system

A rectilinear antenna array is called an array in which the phase centres of the transmitters are located along a straight line - the array axis. Antenna array have several advantages over other types of antennas [[28]–[30]:

- easy-to-operate control of the antenna pattern beam and the direction of the main beam by changing the amplitude and phase of the field transmitted by each antenna array transmitter;

- increasing the radiation power of the antenna array by the spatial addition of fields of individual radiators;

- using of the optimal arrangement of the elements of the antenna array in which they can be arranged in a non-detrimental manner and adaptively changes their location depending on the situation.

Given the aforementioned advantages of antenna array to improve the detection efficiency of low visibility air objects it is proposed combine the independent radars into a radar network – a synchronous coherent multi-radar system based on the principles of sparse antenna array. This paper will analyse the possibilities of improving the detection efficiency multi of air objects when integrating several autonomous radar surveillance into a synchronous coherent multi-radar system. To enable the implementation of multi-positional detection methods and to determine the location of the air objects when integrating surveillance autonomous radar in multi radar system with compatible reception, it is necessary to fulfil the condition of air objects monitoring simultaneously with all radars. We limit the number of radars in the multi radar system to four. A quantitative indicator of the possibility of simultaneous monitoring of air objects by several radars is the overlap ratio of radar detection zones. Fig. 1 shows an example of arrangement and order of scanning a space with one-of-a-kind radar survey radars located at a distance d, their detection zones at a certain height, and the formation of regions of space with an overlapping coefficient K.

In the paper, we focus mainly on the linear or arc method of location elements. If the location of the antenna array elements remains unchanged along the entire system, the antenna array is equidistant.

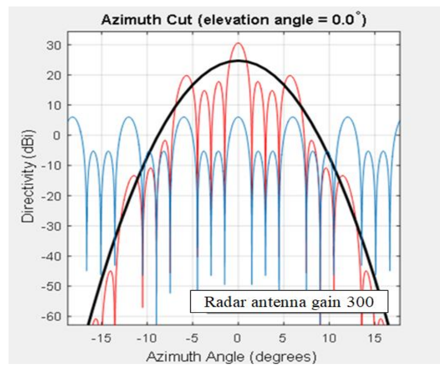
As single-type surveillance radar, we select the radar of the meter range (the antenna beam width is 6˚, the antenna gain - 24.71 dB (300 times)). We define the minimum distance of the radar location in the nodes of the antenna array d = 20 m. This distance exceeds the half-wave length $\lambda / 2$, which causes the formation of sparse antenna array.

It is known [11], [12]–[14] that the multiplier of sparse antenna array is characterized by the presence of a large number of diffraction maximums. At the same time, a sufficiently narrow main beam of the antenna radiation pattern of autonomous radar, acting as elements of sparsed antenna array, provides suppression of diffraction maximums outside of the main beam of the antenna radiation pattern autonomous radar. The results of calculating the antenna radiation pattern of sparsed antenna array, which is formed in a synchronous-coherent system with 4 autonomous radars are shown (Fig. 2).

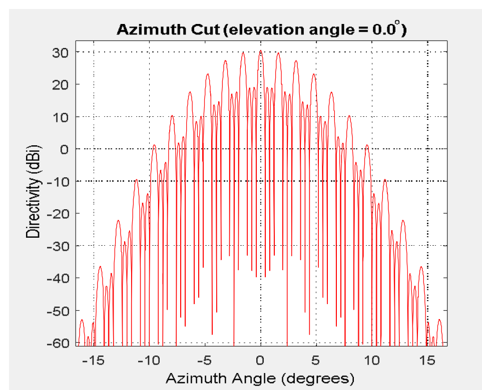
The number of side lobes between the diffraction maximums at in-phase power of the elements of sparse antenna array is determined by the expression: $n_{б.п.} = N - 2$, where N is the number of elements of antenna array. Consequently, in the sparsed antenna array, which is formed from two elements, there are no side lobes.

The width of the main beam at the half-power level of 0.5P is determined by the expression (1):

$$2\theta_{0.5} = 51\frac{\lambda}{Nd}, \text{[degree]} \qquad (1)$$



a)



b)

Figure 2: Creation of the resulting antenna pattern beam of sparse antenna array, which is formed by combining four autonomous surveillance radars into a synchronous coherent multiradar system: a) antenna pattern beam of sparse antenna array at d = 20 m; b) antenna pattern beam of sparse antenna array at d = 60 m

Thus, it is evident that the larger the linear dimensions has antenna array ($L \approx Nd$), the more narrower the main pattern beam. Obviously, the gain of a linear antenna array is proportional to its length.

As can be seen (Fig. 2b) the main beam of sparse antenna array, which is formed in the synchronous coherent system of autonomous radar in the case of a minimum distance between the radar, will consist of three components: the central beam; the first two side lobes; third side lobe. The gain of the central beam of the sparsed antenna array is 30.57 dB (1140 times)

The antenna pattern beam of a multiplier antenna array is denoted by blue, the antenna pattern beam of autonomous radar is indicated by black, and the resulting antenna pattern beam of the sparse antenna array is indicated by red (Fig. 2. a). Creations of antenna pattern beam of antenna array were performed by mathematical modelling in Matlab environment (application toolbar: sensor array analyser) [31].

When combining N autonomous radars into a multi-radar system, an increasing in power emitted by the system pulses is provided and an increasing in the gain of the sparse antenna array (G_N) created in such a system is compared with the antenna gain of the autonomous radar (G_0).

The maximum detection range of separate radars is determined by the expression (2):

$$D_{max} = \sqrt[4]{\frac{P_R \tau_i G_0^2 \sigma \lambda^2}{(4\pi)^3 k_n k k_p T_0}} \qquad (2)$$

where P_R – pulse power transmitter radar;

τ_i – pulse duration;

σ – effective surface of the dispersal of the aircraft;

k_n – noise ratio;

k_p – coefficient of differentiation;

k – Boltzmann constant;

T_0 – absolute temperature.

Given expression (2) and the fact that the complexation of signals is carried out after noiseless amplifiers, the ratio of the maximum detection distance of the autonomous radar (D_{max0}) and multiradar system, which is created by complexing N autonomous radar (D_{max}), is defined by the expression (3):

$$D_{max} = D_{max\,0} \sqrt[4]{\frac{N G_N^2}{G_0^2}} \qquad (3)$$

The expression (3) shows that the antenna aperture square of the system for receiving has increased N times, the antenna gain $\mathbf{G_N}$ has increased relative to the autonomous radar, its value can be obtained from the graph (Fig. 2a).

The directional diagrams of typical autonomous radar are shown (Fig. 3). The main beam width of antenna pattern equal 6 degrees on the half level power and antenna gain G_0=24.74dB.

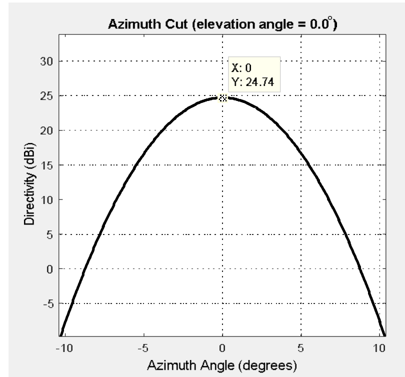
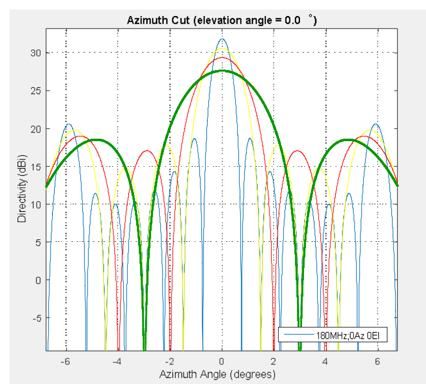
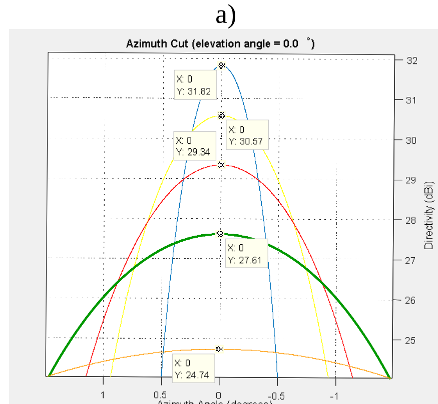


Figure 3: Pattern autonomous radar beam that is an element of the radar system

The directional diagrams of radar system based on surveillance autonomous radar are shown (Fig. 4). The calculations are made for the case of equidistant antenna array at a distance between the nodes of the array 20 m. The creation of the antenna pattern beam is performed with the theory of the sparse antenna array.The radar system of two radars does not have side lobes (Fig. 4a), but each subsequent radar that is added to the system increases by one the number of lateral lobes (Fig. 4b). Increasing the number of radars enables for a higher antenna gain and a narrower main beam shape (Fig. 4). Possibility of increasing the maximum detection range (3) of small radar visibility UAVs when complexing N.



a)



b)

Figure 4: Determining the antenna gain and beam pattern radar system form: a) blue - antenna pattern beam of sparse antenna array (from 8 Radars); b) the main beams of antenna pattern beam of sparse antenna array(antenna gain)

The value of ($Dmax._{N}/Dmax._{N-1}$) specific gravity in increasing the range of detection of air objects shows that each subsequent radar is less effective than the previous one. The fourth radar increases the detection range of the system by 23.77%, and the addition of the next four more radars increases the effect by 37.32%. This demonstrates the economic feasibility of creating a coherent radar system that will consist of 2 to four radars, depending on the requirements and the capabilities available.

The existing system of maintenance and repair of electronic equipment is imperfect, due to the unsuitability of diagnostic support, which consists of methods and means of diagnosis, documentation and maintenance personnel, to the conditions of repair. The use of functional diagnostics techniques that are widely applied to the objects of radio-electronic equipment being exploited make it difficult to determine the true state of the art and to predict it with high probability.

This is caused by the "natural" difficulties of diagnosis, due to the fact that the output of the digital device will generate a response (sequence of pulses), which corresponds to its good technical condition in the presence of both good electronic components, and those that have critical values or characteristics, characteristics who are approaching them. For this reason, it is difficult to predict the time of failure of components of electronic equipment using known methods. Physical diagnostics methods (energy dynamic, energy static, electromagnetic), which, unlike functional ones, allow to determine the real technical state of digital devices of units of electronic equipment. Integrated use of these methods of physical diagnosis enables high probability, which is especially important for critical infrastructure objects.

Within the limits of carrying out of researches on reliability of different groups of radio-electronic components the forced tests were carried out, as a result of which the approximate dependences of values of diagnostic parameters on time, which have curvilinear character, reflecting degradation processes in semiconductors, were obtained. Using the values of the diagnostic parameters as reference allows to determine with a certain probability the real technical condition of the radio-electronic components on the basis of comparison of these values with those obtained as a result of diagnosis during the operation of samples of radio-electronic equipment. In addition, the presence of these values makes it possible to predict the technical condition and determine the residual life of digital devices units of electronic equipment.

The combination of these methods of diagnosis with the results of forced tests on the reliability of radio-electronic components, as well as the developed methods of processing diagnostic information is a new methodology that should be used to build an automated system for technical diagnostics of electronic technology.
The implementation of physical diagnostics at the first level of the maintenance and repair system (at the level of the object of radio-electronic equipment) requires equipping it with appropriate diagnostic devices and computers. Diagnostic information obtained through the use of physical diagnostics during the operation of radioelectronic objects (a posteriori) is fed to the knowledge base of the intelligent diagnosis system as an element of the diagnostic information processing center, which is the second level of the maintenance and repair system.

The Intelligent Diagnostic System database contains the values of the diagnostic parameters obtained during the forced tests (a priori information). Comparison of posterior and a priori information allows correction of the dependencies of diagnostic parameters, which in turn will lead to an increase in the probability of diagnosis and prognosis of the technical condition.

The introduction of a new automated system of shadow diagnosis makes it possible to determine the actual technical condition of the digital device, creates acceptable conditions for the implementation of impersonal repair, which meets the requirements of the leading technical material for maintainability, to prevent failures with a sufficiently high likelihood and to prolong the life of the device by means of blocks , which will result in a 10-15% increase in the readiness factor, which is the readiness factor.

The timely detection and replacement of digital devices that contain integrated circuits with critical characteristics avoids the sudden failure of electronic equipment units, which is relevant for electronic equipment of critical infrastructure objects, as failure of their components can lead to catastrophic consequences. In addition, the new automated system of technical diagnostics allows to reduce the multiplicity of redundancy of equipment of objects of electronic equipment, which in the difficult economic conditions of the state saves the money spent on repeated reservation of its blocks.

5. CONCLUSION

Based on the results of the mathematical modelling of the multiradar system, it can be concluded that the integration of several autonomous radars into a coherent multiradar system will enable to use systemic effects for increasing the detection range of small-sized air objects depending on the level of consistency realization in the system. This is due to the increase in energy potential and the use of properties of sparse antenna arrays that can be formed in such a system. The issue of coordinated inspection is solved by synchronous rotation in the system. Each new additional radar of the system adds power to the whole system, but its share in the overall effect decreases. The optimum number of radars of the system is no more than 4. The detection range will be increased maximum to 2.76 times.

Suggestions for construction of an automated system for technical diagnostics of objects of radio-electronic equipment on the example of radars.

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